EFFECTS OF THERMOPERIOD ON THE STOMATAL OPENING AND TRANSPIRATION OF PINEAPPLE (Ananas comosus (L.) Merr.)

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN AGRONOMY

AUGUST 1969

By

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ACKNOWLEDGMENT

The author wishes to express his thanks to Pineapple Research Institute for the plant material used in the research for this thesis.

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CHAPTER I

INTRODUCTION

The more extensive studies of pineapple (Ananas comosus (L.) Merr.), to date, have been done by the Pineapple Research Institute (P.R.I.) in Hawaii. Many of these studies were undertaken as a result of field problems.

The subject of pineapple water relations has received little attention in Hawaii or elsewhere because the crop is grown in tropical and subtropical areas where rainfall generally is adequate. In addition, the water use rate and drouth tolerance of pineapple are such that it can withstand prolonged dry periods with minimal adverse effects. Unpublished data from the P.R.I. and comments by researchers who have traveled to other areas of the world observing pineapple cultural practices indicate reduced amounts of leaf water storage tissue are associated with climates having quite high temperatures and little diurnal variation.

The variability in water storage tissue associated with climatic variations raised the question of variations in water use under different day-night temperature regimes. With increased interest in cropping areas having arid environments and the recognition of water as a limited resource it was deemed desirable to examine the environmental responses of the pineapple plant under controlled conditions. With specific knowledge about the environmental responses of this plant it may be possible to predict water use patterns and rates under a given environment.

This study was designed to gain an understanding of pineapple plant transpiration cycles and rates under various day-night temperature regimes for small plants. From this understanding perhaps experiments can be designed to more clearly delineate the climate effects on pineapple plant growth and fruit production.

The objectives of this study were as follows:

1. Find a simple, accurate and nondestructive method of determining the leaf area of pineapple plants.
2. Determine the effects of thermoperiod on diurnal variation of transpiration and stomatal opening cycles in young pineapple plants.
3. Determine the effects of thermoperiod on day and night transpiration in young pineapple plants.

CHAPTER II

REVIEW OF LITERATURE

Leaf Area Determination

To study the patterns of transpiration from plants a common base of leaf area needs to be established. Various workers have developed several methods of estimating the leaf area of pineapple plants. Krauss (1930) estimated the leaf area of pineapple using formulas to calculate area from leaf length and width of trapazoidal and triangular leaves, the two general leaf shapes found in pineapple. Ekern (1965) determined the leaf area of pineapple by stripping the leaves, tracing them on cardboard or photographic paper, cutting out the shapes, and weighing the cut-outs. The leaf area was then obtained using an area-weight relationship derived from a standard area of cardboard or photographic paper. Joshi et al. (1965) used the relationship between leaf area and leaf dry weight to estimate the leaf area from the lead dry weights of pineapple.

Non-destructive methods for determining the leaf area of several other plant species have been developed. Wendt (1967) discovered a relationship existed between the logarithm of leaf area and the logarithm of leaf length for several crops. He reported a simple correlation coefficient (r) between the logarithm of leaf area and the logarithm of leaf length of 0.95 for cotton, 0.99 for castor beans, and 0.94 for sorghums. Several varieties were included in each of these values. Necas et al. (1967) reported correlation coefficients between leaf area and leaf length ranging from 0.83 to 0.98 for potato leaves. Linear, semilogarithm and hologarithm relationships between leaf length and leaf area were examined with the highest correlation being obtained for the hologarithm relationship.

Transpiration Determinations

The transpiration rate of the pineapple plant ranges from 10 to 100 times less than most crop plants. Ekern (1965) found evapotranspiration rates of 0.3 to 0.5 mg water/cm^2 leaf area/hour with pineapple and cited transpiration rates of 26 mg/cm^2/hr with corn and 43 mg/cm^2/hr for cocklebur. Joshi et al. (1965) found transpiration rates of 0.02 to 0.05 g/100 cm^2/hr for pineapple and cited rates of 0.5 to 0.6 g/100 cm^2/hr for corn, 0.8 to 0.9 g/100 cm^2/hr for milo and 0.8 to 0.9 g/100 cm^2/hr for cotton.

Krauss (1930), Ekern (1965), Joshi et al. (1965), and Neals et al. (1968), measured the diurnal transpiration of pineapple outdoors with wind and rain protection, in a lysimeter, in a greenhouse, and in a perspex chamber respectively. From these measurements a pattern of restricted water loss in the forenoon with higher afternoon and early evening transpiration appeared. Kent[1] using detached leaves, found that stomata were closed in the morning and opened progressively from mid-afternoon to evening. These reports show there is a diurnal pattern in the transpiration rate and stomatal behavior of pineapple under the environments examined by the abovementioned experimentors.

Neals et al. (1968) studied the diurnal patterns of transpiration and carbon assimilation for several xerophytes including pineapple under

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[1]Kent, M. J., Honolulu, Hawaii, Private Communication, 1967.

controlled environment conditions. They showed that CO_2 uptake cycles closely followed transpiration cycles and peak CO_2 uptake and water loss occurred during the middle of the day.

Temperature effects on stomatal opening generally have been shown to be negligible except as they affect leaf turgor and effects on transpiration are directly related to the water vapor content of the air. Pallas et al. (1967) and Slayter and Bierhuizen (1967) have shown a positive correlation between transpiration of cotton and the water vapor pressure deficit of the air, but no specific temperature effects on stomatal opening were observed.

Ting et al. (1967), however, showed that Kalanchoe blossfeldiana had a low day and high night leaf resistance when "pretreated with cool thermoperiods, or with thermoperiods having little diurnal temperature fluctuation." They also stated that "large diurnal temperature fluctuations resulted in apparent nocturnal stomatal opening," but the lowest leaf resistances were actually measured during the day. It was concluded from the observed leaf resistances (20 to 60 sec/cm) at night that the stomates were essentially closed at all times during the night period.

A relative measure of the evaporating power of the air is a critical factor in evaluating stomatal behavior where the stomates cannot be observed directly and constant humidity chambers are not available. Porous porcelain spheres, plates, or discs (atmometers), which present a water surface to the air provide a way to measure the evaporative demand of the environment. The units are both white and black so sunlight can be evaluated with respect to evaporation. Livingston (1935) reported that black atmometers integrate the effects of sunlight, relative humidity, and air movement, while white atmometers integrate all but the effect of sunlight into one measurement of the evaporating power of the air.

CHAPTER III

MATERIALS AND METHODS

Leaf Area Determination

To develop a regression equation relating leaf length to leaf area of pineapple, the following method was used. Leaf length was measured on intact pineapple plants with a meter stick to the nearest 0.1 cm (Figure 1). The measured leaves were then numbered and stripped from the plants. The basal white tissue was removed as was done by Krauss (1930) (Figure 2). The measured, numbered leaves with basal white tissue removed were outlined on paper and numbered for further identification. The leaf outlines were then cut out with scissors and weighed to the nearest 0.0001 grams on an analytical balance. Finally, leaf area was determined by multiplying weight of the leaf outlines by the weight of a square centimeter of paper. Paper weight per square centimeter was determined by weighing a standard area of paper, generally two hundred square centimeters, and dividing by the area.

The relationship between leaf area and leaf length was obtained by plotting these parameters on a graph. Regression analysis based on 224 leaves was used to obtain an equation which described this relationship. This equation was then used to estimate the leaf area of experimental plants from leaf lengths measured *in situ*.

Growing and Maintenance of the Plants

Pineapple crowns of a Cayenne clone were rooted in water for approximately two months. It was observed that during this period the phylotaxy which was similar to the fruit at the time of harvest, reverted

FIGURE 1. LEAF LENGTH MEASUREMENT ON AN INTACT PINEAPPLE PLANT.

FIGURE 2. PINEAPPLE LEAF SHOWING BASAL WHITE TISSUE REMOVED PRIOR TO LEAF AREA DETERMINATION.

from that of the crown to that of a normal pineapple plant.

After approximately two months the dead and early crown leaves were stripped off the rooted plants. The plants which were about 1/10 the size of full grown field plants, were carefully inserted into 500 ml widemouth Erylenmeyer flasks. To keep algal growth to a minimum the flasks had been painted black to reduce light transmission, then white to maintain temperature near that of the air. A window was provided on the side of the flask so the nutrient culture solution level could be observed. Next, three glass tubes were inserted into the flask, one of which was long enough to reach the flask bottom and served as an aerator. The two short air outlet tubes were also used for refilling the flasks with nutrient culture solution (Figure 3). The flasks were filled with water to the base of the stem or until all the roots were covered. Warm melted wax was poured into the remaining space in the flask around the base of the plant and aeration tubes.

After solidifying, the wax supported the plant and sealed the flask, preventing direct evaporation. This method did not result in any observable plant damage. Finally, plastic electricians tape was wrapped around the top of the flask partially covering the wax sealer for added support (Figure 4). After sealing the plants into the flasks, about 300 ml of nutrient culture solution were added. A mark was put beside the observation window at the 300 ml mark so the water level could be consistently returned to the original volume. Aeration was accomplished by bubbling air through the long tube provided. Water lost from the flask was replaced daily.

FIGURE 3. ROOTED CROWN, GLASS TUBES, AND FLASK BEFORE ASSEMBLY.

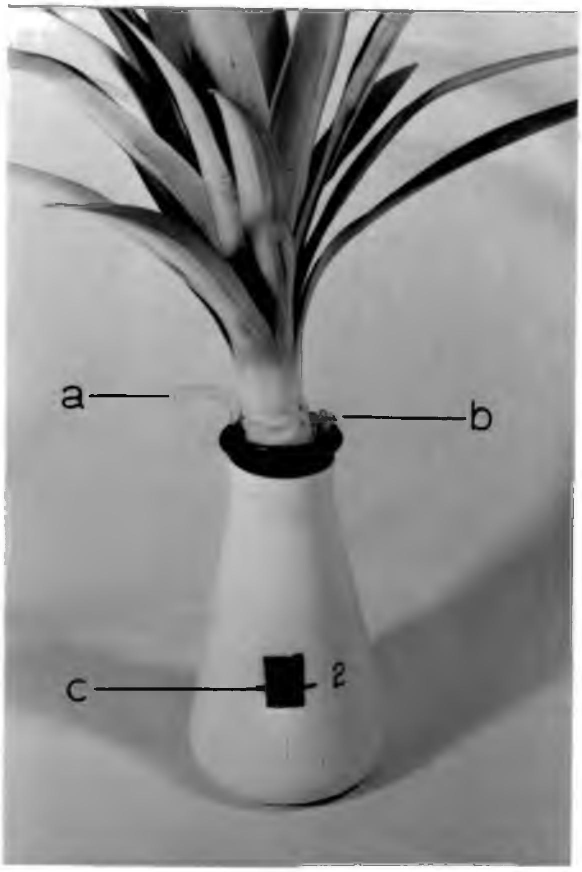

FIGURE 4. PINEAPPLE CROWN SEALED INTO FLASK. a) AERATION INLET, b) AIR OUTLET, c) OBSERVATION WINDOW WITH SOLUTION LEVEL MARKS.

The nutrient culture solution was made up as shown in Table I. Solutions were changed weekly or as often as was deemed necessary.

The experiments were conducted in a controlled environment chamber with light intensities maintained between 3500 and 4000 foot-candles at mid-plant height. The light intensity was approximately equivalent to a day with full cloud cover. Desired temperatures were maintained within ± 1°C. Twelve hour day-night cycles were maintained for all temperature combinations. A dehumidifier was used to maintain increased and near constant evaporation rates in the chamber. A black, spherical, 0.81 atmometer provided a measure of the evaporating power of the chamber environment. No attempt was made to hold the atmometer rate constant between day and night periods. Plants were placed in the controlled environment chamber four to six days before observations were begun to allow for adjustment to the controlled environment. Aeration was not used during the 24 hours of the experiment.

Transpiration and Stomatal Opening Cycle Studies

Hourly gravimetric water loss measurements were made over a 24 hour period to characterize transpiration and stomatal opening cycles. Hourly atmometer water losses were recorded to characterize the evaporative power of the chamber environment. The atmometer and a thermometer were located at mid plant height to ensure that the plant environment was accurately evaluated.

Night temperatures of 15, 20, 25, 30, and 35°C were used at a constant day temperature of 25°C. With the 35°C day temperature, night temperatures of 20, 25, 30 and 35°C were used. Four plants were used for each day-night temperature combination.

TABLE I. NUTRIENT CULTURE SOLUTION*

Stock Solutions Make each of the following to 1 liter		Mililiters stock solution to make 10 liters of Nutrient Culture Solution
NH_4NO_3	39.98 g	50
K_2SO_4	44.60 g	20
KH_2PO_4	65.85 g	10
$MgSO_4 \cdot 7H_2O$	202.80 g	10
$CaCl_2 \cdot 2H_2O$	55.40 g	10
Micronutrient Stock Solution Make the following to 1 liter		2.5
H_3BO_4	2.86 g	
$MnCl_2 \cdot 4H_2O$	1.81 g	
$CuSO_4 \cdot 5H_2O$	0.08 g	
$ZnSO_4 \cdot 7H_2O$	0.22 g	
Na_2MoO_4	0.50 g	
Chelate 138 (Fe)	50.00 g	

*Sanford, W. G., Honolulu, Hawaii, Private Communication, 1968.

Leaf lengths were measured before and after each experiment and leaf area was estimated using the regression equation developed from the leaf area determination studies.

Day-Night Transpiration Comparison Studies

In addition to hourly measurements made at various temperature combinations, day and night weight loss measurements were made at constant temperatures of 20, 25, 30 and 35°C and a 35°C day with a 15°C night. Gravimetric determinations of water loss for the night period were made just after chamber lights were turned on, and for the day period just after chamber lights were turned off.

The same four plants were used throughout this series. After a five day acclimation period in the chamber, water loss was recorded for the first temperature regime. Immediately after the last reading, the nutrient culture solution was changed and the chamber readjusted for the next temperature regime. On the fourth day following this adjustment, water losses were recorded and the procedure repeated.

CHAPTER IV

RESULTS

Leaf Area Determination

Leaf lengths and leaf areas were determined for two pineapple clones. Of the equations used in attempting to describe the data (Table II), the best fit was obtained with the hologarithmic equation $\log_e \hat{Y} = a + b \log_e X$, where $\hat{Y}$ is the estimated leaf area and X is the measured leaf length. The semilogarithmic equation $\hat{Y} = a + b \log_e X$ gave the poorest fit to the data of the four equations used.

The equation used to calculate leaf areas of the small plants in the transpiration experiments was $\hat{Y} = -3.26 + 2.06X + 0.0204X^2$ where $\hat{Y}$ is the estimated leaf area and X and X^2 are the leaf length and leaf length squared (Figure 5). Because the data was somewhat curvilinear and the difference between the three best correlation coefficients was small, the multiple regression equation was used.

Effects of Thermoperiod on Hourly Transpiration

Transpiration at nine temperature combinations was examined by taking 24 hourly gravimetric measurements on four plants (Appendix I). A black, spherical, 0.81 atmometer was used to characterize the evaporating power of the environment. A ratio of transpiration in $g/dm^2/hr$ over uncorrected atmometer in ml/hr was then calculated to approximate a constant evaporative potential. It should be noted that the ratio is a pure number because the area of the atmometer can be determined. Where the evaporative potential was relatively constant both day and night (Figure 7, top), the calculation of the ratio would

TABLE II. REGRESSION EQUATIONS AND CORRELATION COEFFICIENTS DESCRIBING THE RELATIONSHIP BETWEEN LEAF LENGTH AND LEAF AREA FOR PINEAPPLE

Clone	Regression Equation	Correlation Coefficient	Number of Observations
Hybrid (large field grown plants)	$\hat{Y} = -131+8.39X$	0.966	40
	$\hat{Y} = -691+257 \log_e X$	0.859	40
	$\log_e \hat{Y} = -0.468+8.39 \log_e X$	0.986	40
	$\hat{Y} = 18.8+0.89X+0.074X^2$	0.92	40
Smooth Cayenne (large field grown plants)	$\hat{Y} = -120+7.15X$	0.938	116
	$\hat{Y} = -786+274 \log_e X$	0.843	116
	$\log_e \hat{Y} = -0.545+1.51 \log_e X$	0.971	116
	$\hat{Y} = 33.1-0.58X+0.068X^2$	0.96	116
Smooth Cayenne (Experimental Plants)	$\hat{Y} = -11.0+2.91X$	0.964	224
	$\hat{Y} = -78.9+43.7 \log_e X$	0.887	224
	$\log_e \hat{Y} = -0.260+1.36 \log_e X$	0.972	224
	$\hat{Y} = -3.26+2.06X+0.0204X^2$	0.964	224

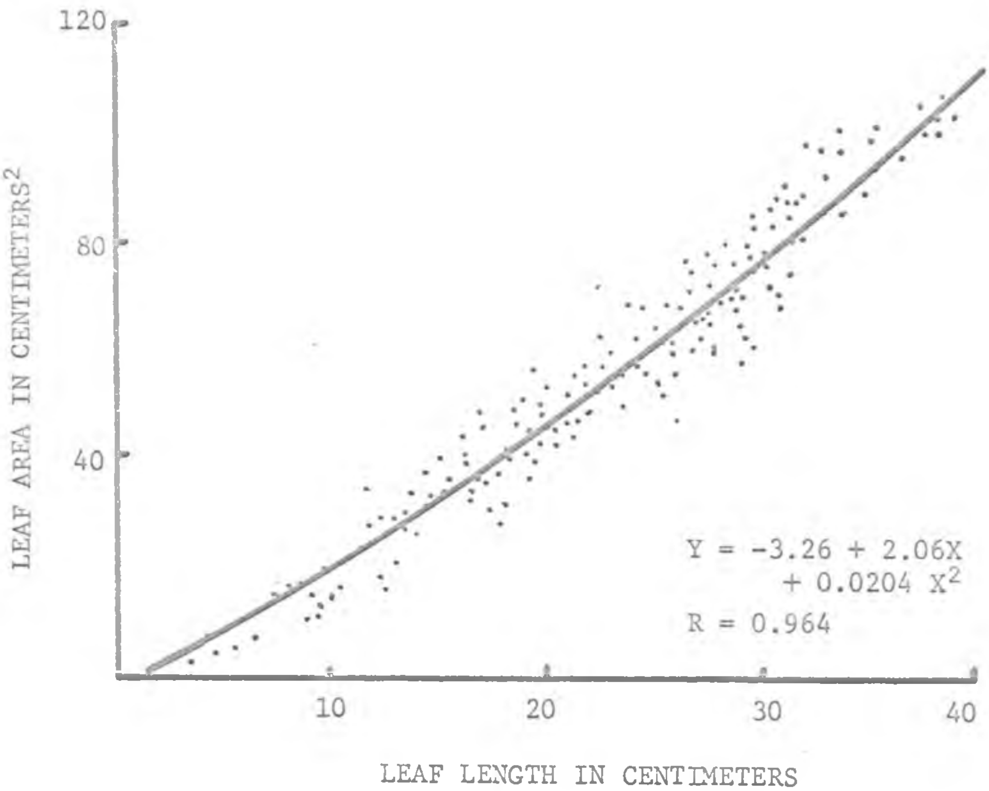

FIGURE 5. RELATIONSHIP BETWEEN LEAF LENGTH AND LEAF AREA OF PINEAPPLE.

only affect the magnitude of the values obtained. However, where there was a large difference in evaporative potential between the dark and light periods (Figure 6, top), the ratio corrected transpiration for the reduced evaporative demand and allowed a more accurate evaluation of plant response to temperature. Considerable plant to plant variation in transpiration was observed at times, part of which could be attributed to differences in plant leaf area (Appendix I).

Figure 6 shows transpiration rates, atmometer rates, and the ratios for a day temperature of 35°C with varying night temperatures. At about 1930, one and one half hours after lights off, the ratio jumped to the characteristic peak seen at all temperature combinations examined in this series. Average night transpiration/atmometer ratios were higher than those during the day (Table III) and in two of the four 24 hour periods, absolute day transpiration was higher than night transpiration while in the other two the reverse was true. The atmometer averaged higher during the day than at night at all temperature combinations (Table III).

At a constant day-night temperature of 35°C (Figure 6, upper left), transpiration closely followed the atmometer with the highest rates in mid-afternoon. Average transpiration rates (the dashed line across the graphs) were higher for the day than the night. Atmometer rates averaged higher in the day than at night and resulted in a ratio which was slightly higher at night than during the day.

At a night temperature of 30°C (Figure 6, upper right) the transpiration rate increased to a maximum at about 1330 and then decreased steadily for the duration of the experimental period. The

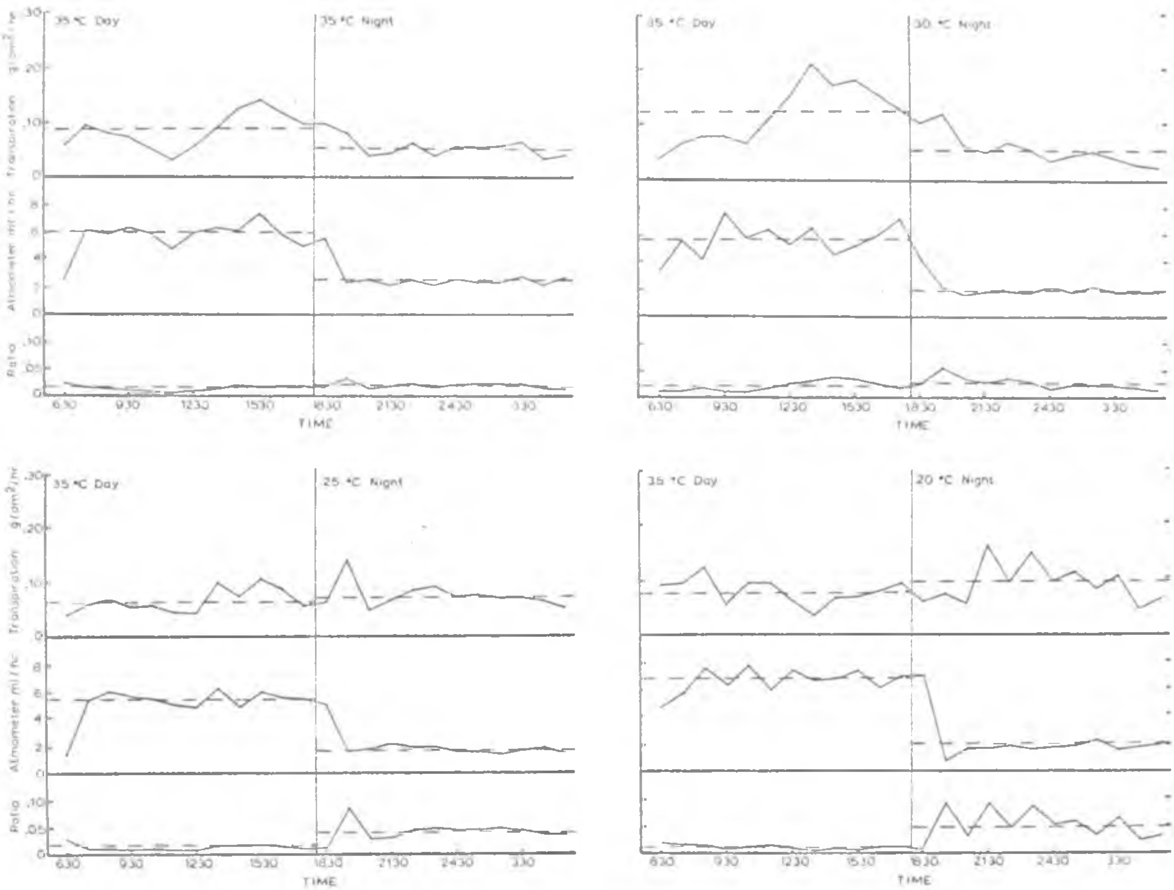

FIGURE 6. TRANSPIRATION, ATMOMETER, AND TRANSPIRATION/ATMOMETER RATIO WITH A 35°C DAY TEMPERATURE AND FOUR NIGHT TEMPERATURES.

TABLE III. AVERAGE DAY AND NIGHT TRANSPIRATION, ATMOMETER AND TRANSPIRATION/ATMOMETER RATIO FOR A 35°C DAY AND VARYING NIGHT TEMPERATURES

Night Temp °C	Day			Night		
	Trans $g/dm^2/hr$	Atmometer ml/hr	Ratio	Trans $g/dm^2/hr$	Atmometer ml/hr	Ratio
35	.087	6.00	.0145	.052	2.48	.0210
30	.124	5.70	.0219	.052	1.96	.0264
25	.064	5.41	.0119	.070	1.66	.0423
20	.075	6.83	.0110	.095	2.00	.0476

average transpiration rate was higher for the light than the dark period while the ratio averaged somewhat higher in the dark.

At a night temperature of 25°C, day transpiration closely followed the atmometer (Figure 6, lower left, and Table III). The average rate for the day was lower and the night rate higher than average rates obtained at day-night temperature combinations of 35°C-35°C and 35°C-25°C. Also, for the first time in the 35°C day temperature series, night transpiration averaged slightly higher than day transpiration. Because the evaporative potential was much higher during the day, the ratio at night was approximately twice that obtained during the day.

At a night temperature of 20°C (Figure 6, lower right), average day transpiration was lower than average night transpiration and no definite mid-afternoon peak was observed. At night the transpiration rate increased rapidly, then fluctuated widely throughout most of the night. The ratio was lower during the day than at night. The night ratio reflected the wide fluctuation seen in the transpiration data and show that the variability was not attributable to the chamber environment.

Figure 7 shows transpiration rates, atmometer rates, and their ratios for five night temperatures at a constant day temperature of 25°C. All day transpiration patterns peaked in early- to mid-afternoon. Day transpiration rates averaged higher than night rates in all cases while the average atmometer rates for the day were about equal to or greater than those for the night (Table IV). Day transpiration and transpiration/atmometer ratio declined with night temperatures of 30°C and below. Night transpiration remained essentially constant and the ratio increased reflecting the reduced evaporative demand at the lower

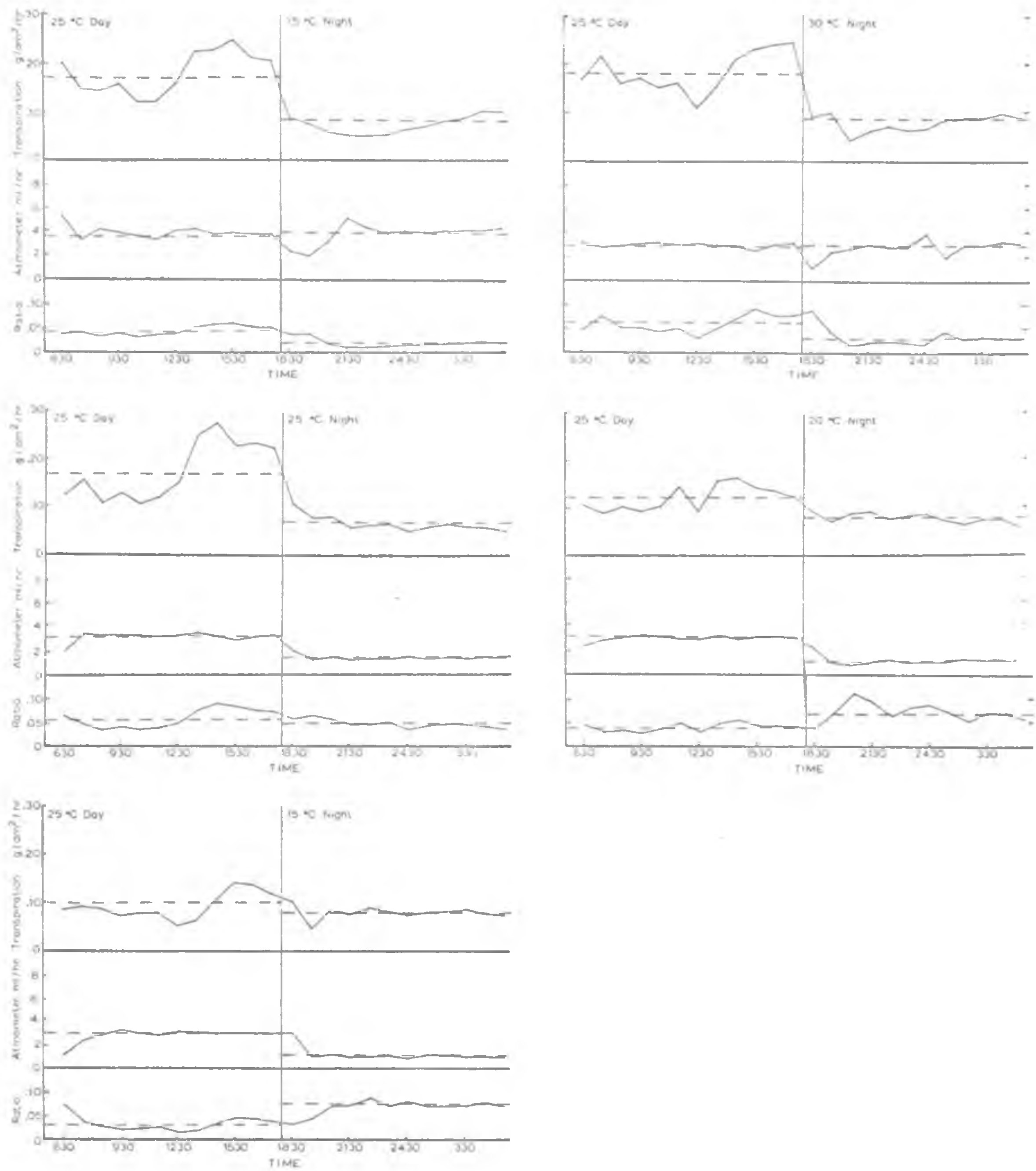

FIGURE 7. TRANSPIRATION, ATMOMETER, AND TRANSPIRATION/ATMOMETER RATIO WITH A 25°C DAY TEMPERATURE AND FIVE NIGHT TEMPERATURES.

TABLE IV. AVERAGE DAY AND AVERAGE NIGHT TRANSPIRATION AND TRANSPIRATION/ATMOMETER RATIO FOR A 25°C DAY AND VARYING NIGHT TEMPERATURES

Night Temp °C	Day			Night		
	Trans $g/dm^2/hr$	Atmometer ml/hr	Ratio	Trans $g/dm^2/hr$	Atmometer ml/hr	Ratio
35	.171	3.69	.0463	.083	4.10	.0202
30	.177	2.81	.0630	.085	2.88	.0295
25	.169	3.02	.0561	.067	1.38	.0489
20	.120	2.97	.0405	.080	1.15	.0691
15	.097	2.98	.0325	.078	1.05	.0748

night temperatures. The day ratios averaged higher than night ratios when night temperatures were greater than or equal to day temperatures, but were less when night temperatures were below the day temperatures.

Day transpiration (35°C night temperature) averaged higher than night transpiration while the atmometer rates averaged slightly higher during the night than during the day (Figure 7, upper left). The ratio averaged higher for the day than for the night.

At a night temperature of 30°C (Figure 7, upper right), day transpiration averaged higher than for the night. Atmometer evaporation rates were essentially constant for the day and the transpiration/atmometer ratio pattern was similar to that observed for transpiration. The day and night atmometer averages were similar and resulted in a higher average day transpiration/atmometer ratio.

Transpiration was also higher during the day than at night at a constant day-night temperature of 25°C (Figure 7, middle left) and the pattern of transpiration was similar to that found at temperature regimes of 25°C day-35°C night and 25°C day-30°C night. The atmometer rate averaged higher during the day than the night and resulted in an average ratio which was slightly higher for the day than for the night.

At 20°C transpiration rates were higher in the day than at night (Figure 7, middle right) and differences between day and night transpiration were not as great as those found for night temperatures which were equal to or greater than the day temperature. The ratio averaged higher during the night than during the day for the first time in this series.

At a night temperature 10°C below the day temperature (Figure 7, lower left) average day transpiration was only slightly higher than at night with the maximum rate occurring at 1530. The atmometer rate was lowest at night, being about one half that obtained during the day. Correcting transpiration for the differential in evaporative potential resulted in a ratio which was higher during the night than the day.

Effects of Thermoperiod on Day-Night Transpiration

Figure 8, Table V and Appendix II summarize the results obtained at the day-night temperature regimes of 20, 25, 30, and 35°C. The data for temperatures of 25°C and 35°C are an average of 12 hourly gravimetric measurements for the day and night period and 12 hour totals taken at the end of the day and night periods.

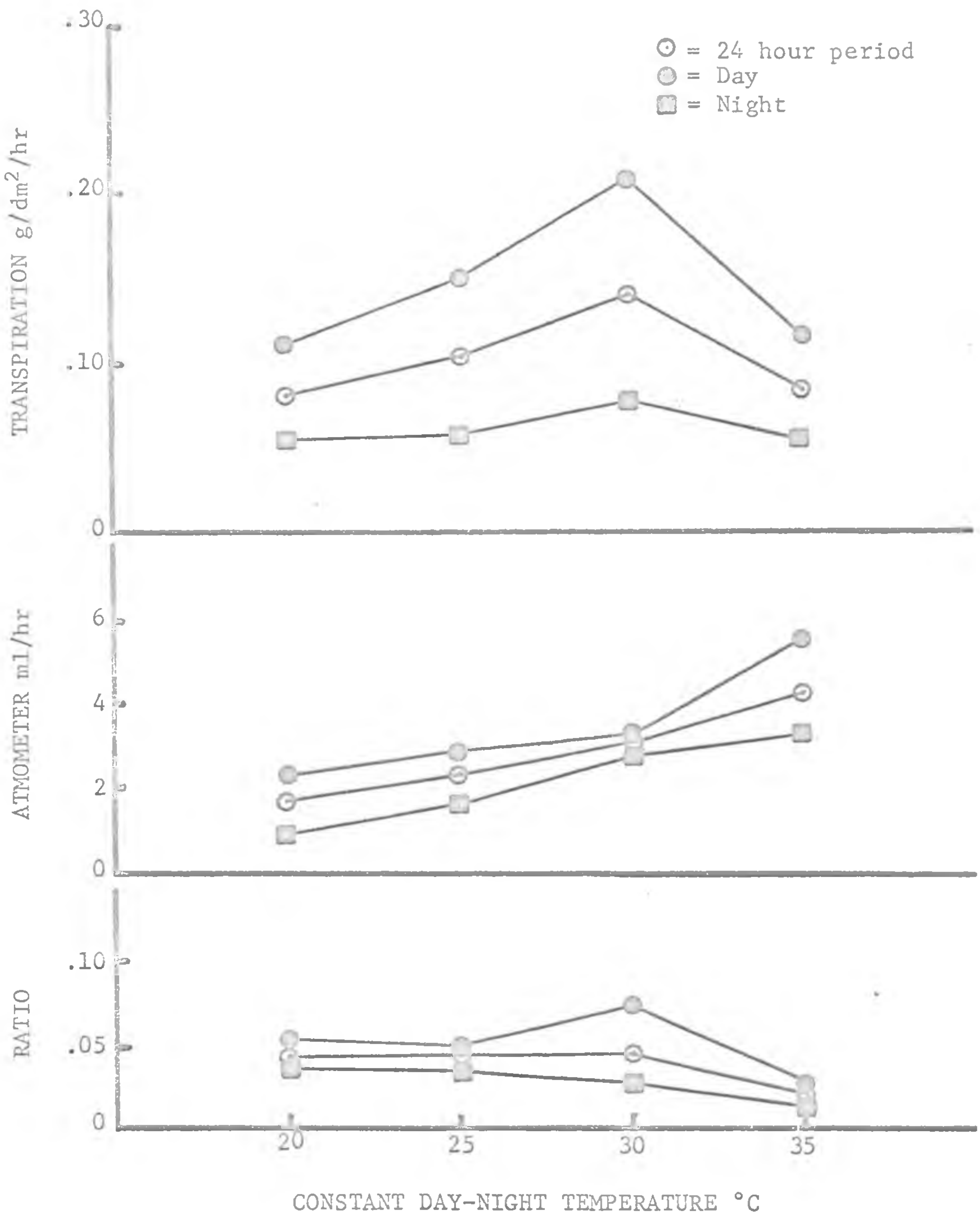

FIGURE 8. TRANSPIRATION, ATMOMETER, AND TRANSPIRATION/ATMOMETER RATIO FOR THE 24 HOUR PERIOD, DAY, AND NIGHT FOR FOUR CONSTANT DAY-NIGHT TEMPERATURES.

TABLE V. THE EFFECT OF FOUR CONSTANT DAY-NIGHT TEMPERATURES ON TRANSPIRATION/ATMOMETER RATIOS

Constant Temp. °C	Ratio
	24 hr Period
35*	.0201 a
25*	.0449 b
20	.0458 b
30	.0460 b
	Day
35*	.0219 a
25*	.0499 b
20	.0506 b
30	.0706 c
	Night
35*	.0187 a
30	.0281 ab
25*	.0369 b
20	.0432 b

*Average of two separate experiments.
Temperatures are listed from lowest to highest ratios. Ratios with the same letter are not significantly different at the 5% level of probability by Duncan's Multiple Range Rest.

Transpiration for the 24 hour period (Figure 8) was highest at 30°C, lowest at 20°C with the values for 25 and 35°C falling between. Much of the variation in the 24 hour averages is attributable to variations in transpiration during the day. Day rates were at least twice as high as the night rates which remained essentially constant at all temperatures. Atmometer rates increased with increasing temperature, the higher rates being obtained during the light period when the evaporative demand was higher.

The ratios declined with increasing temperature indicating that much of the increase in transpiration could be attributed to increasing evaporative demand rather than to decreases in leaf resistance to water vapor transfer. The 24 hour ratio at 35°C was significantly lower than those obtained at 20, 25, and 30°C which were not different from each other (Table V). The day ratios at 35 and 30°C were significantly different from 25 and 20°C ratios and from each other. The 25 and 20°C ratios were not significantly different from each other. The night ratio for 35°C was not significantly lower than the 30°C ratio but was different from those at 25 and 20°C. Other differences were not significant.

Figures 9 and 10, Table VI, and Appendix II summarize the results obtained for day temperatures of 25 and 35°C with night temperatures of 15, 20, 25, 30 and 35°C. The data for 25 and 35°C constant day-night temperatures are an average of two trials as indicated previously.

For a 35°C day, the 24 hour transpiration rates were generally higher at the high night temperatures (Figure 9). Day transpiration rates were about the same as night rates to 25°C and then increased to

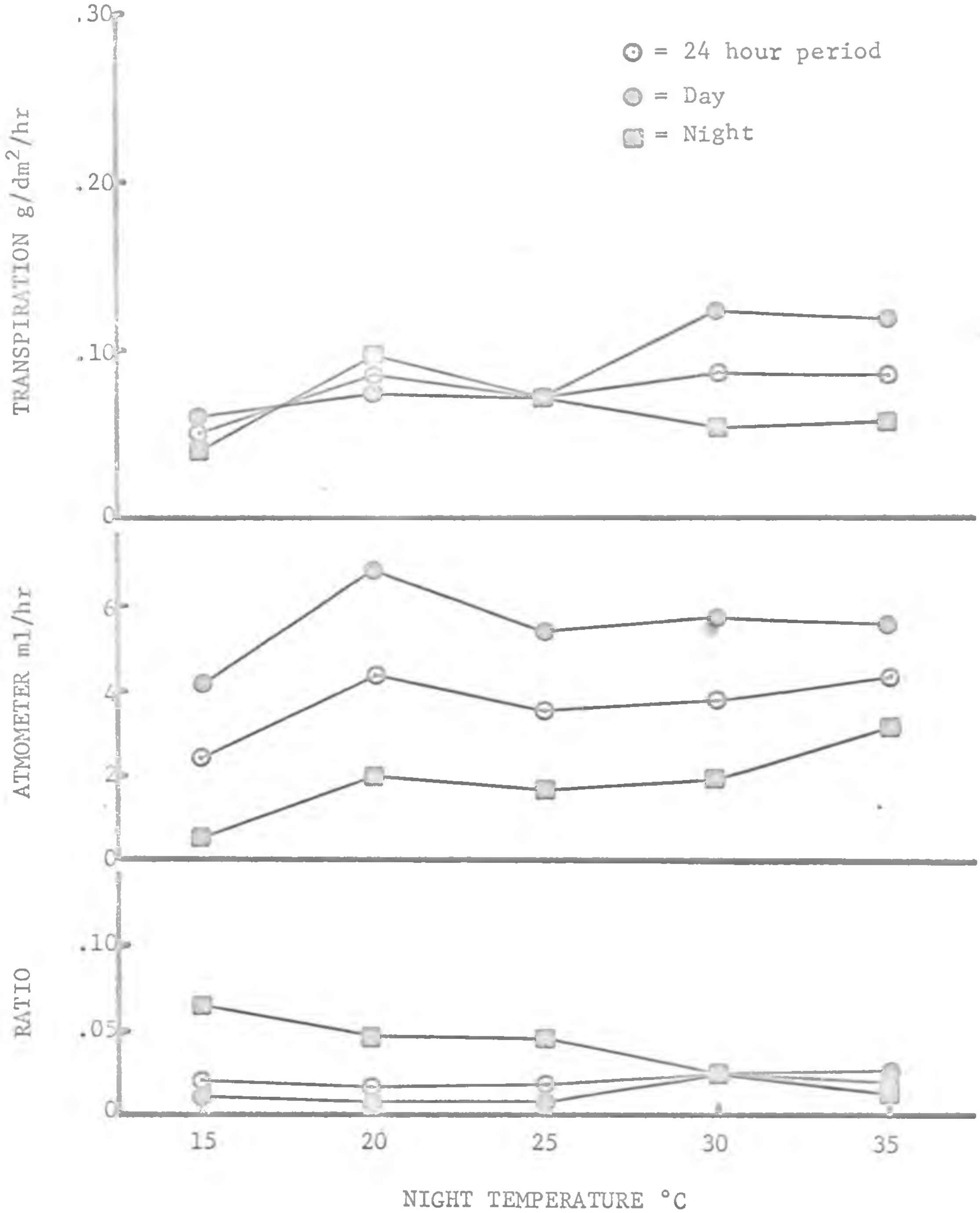

FIGURE 9. TRANSPIRATION, ATMOMETER, AND TRANSPIRATION/ATMOMETER RATIO FOR THE 24 HOUR PERIOD, DAY, AND NIGHT FOR 35°C DAY AND 5 NIGHT TEMPERATURES.

TABLE VI. THE EFFECT OF TWO DAY AND FIVE NIGHT TEMPERATURES ON TRANSPIRATION/ATMOMETER RATIOS

35°C Day Temp		25°C Day Temp	
Night Temp °C	Ratio	Night Temp °C	Ratio
	24 hr period		
25	.0190 a	35	.0326 a
20	.0193 a	15	.0436 ab
35*	.0201 a	25*	.0449 ab
15	.0216 a	30	.0461 ab
30	.0230 a	20	.0485 b
	Day		
20	.0110 a	15	.0325 a
25	.0119 a	20	.0405 ab
15	.0147 a	35	.0463 ab
30	.0219 a	25*	.0499 bc
35*	.0219 a	30	.0630 c
	Night		
35*	.0187 a	35	.0202 a
30	.0264 a	30	.0295 ab
25	.0423 b	25*	.0369 b
20	.0476 b	20	.0691 c
15	.0640 c	15	.0748 c

*Average of two separate experiments. Temperatures are arranged in order of the lowest to the highest ratios. Ratios with the same letter are not significantly different at the 5% level of probability by Duncan's Multiple Range Test.

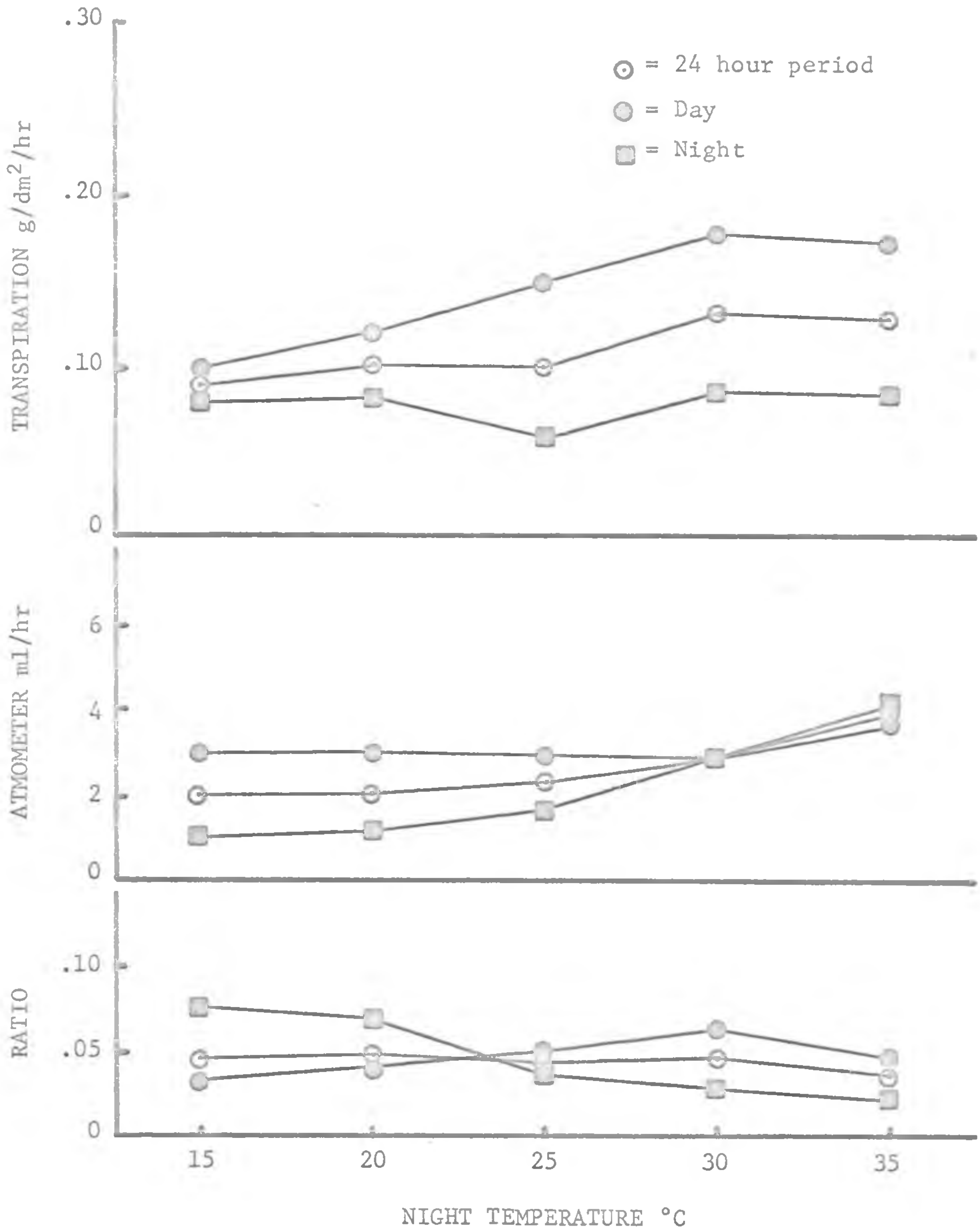

FIGURE 10. TRANSPIRATION, ATMOMETER, AND TRANSPIRATION/ATMOMETER RATIO FOR THE 24 HOUR PERIOD, DAY, AND NIGHT FOR 25°C DAY AND 5 NIGHT TEMPERATURES.

approximately twice the night rates at 30 and 35°C. No consistent trends were apparent in the night transpiration data. Day, night and 24 hour atmometer rates generally increased with increasing night temperature. No significant trends were observed for the day or 24 hour ratios (Table VI). The night ratios which declined with increasing night temperature, were greater than the day ratios at temperatures of 15, 20, and 25°C. Increasing leaf resistance with increasing night temperatures is indicated. The night ratio at 15°C was significantly greater than those at the other night temperatures. The ratios at 20 and 25°C were greater than at 30 and 35°C but not different from each other. The ratios at 30 and 35°C were not significantly different from each other.

At a 25°C day temperature, day transpiration rates increased with increasing night temperature and the same trend is reflected in the 24 hour averages. Night transpiration rates were lower than those during the day and remained nearly constant at all temperatures. Day atmometer rates were constant to 30°C and then increased while night rates increased with increasing temperature. The ratios were greater at night than during the day at 15 and 20°C while the day ratios were larger at 25, 30 and 35°C. It is likely that changes in both leaf resistance and evaporative demand occurred as night temperatures increased. For the 24 hour period, the highest ratio at 20°C was only significantly greater than the ratio at 35°C (Table VI). Significant differences were also observed among day and night ratios.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Leaf Area Determination

The high correlation obtained between leaf area and leaf length show that leaf area of a pineapple plant can be closely approximated by measuring only one parameter of each leaf, leaf length, and can thus replace other methods of estimating leaf area.

Wendt (1967) and Necas et al. (1967) obtained the highest correlations between leaf length and leaf area by using the logarithms of both values. The hologarithmic relationship also gave the highest correlations for pineapple leaves.

For most work in pineapple transpiration and carbon assimilation, this approach to leaf area determination appears quite adequate. After the initial work of determining the regression line of best fit it is quite easily applied to the experimental plants.

Effects of Thermoperiod on Hourly Transpiration

Evaporation can occur only when a water vapor pressure gradient exists between a source of water and the air in the surrounding environment. The rate of evaporation is a direct function of the steepness of the vapor pressure gradient. This same condition must also hold in order for transpiration to occur, but plant factors which include the effective length of the path from the evaporating surface inside the leaf to the atmosphere, and the diameter and number of stomata.

In Hawaii, high relative humidities at night essentially preclude night transpiration from plants even though stomata may be open.

Therefore, in this study the relative humidity of the growth chamber was reduced and stabilized with a dehumidifier. A measure of the evaporative demand of the environment in both the day and night was obtained with a black spherical atmometer. With the atmometer as a guide to environment evaporative demand, plant transpiration could be corrected so that transpiration data could be presented as an assumed function of leaf resistance rather than as a function of varying relative humidities. Atmometer rates of 4.93 and 1.80 ml/hr, which were the 24 hour extremes for the experiments, when converted to a per day basis would be approximately comparable to standard Class A Pan rates of 0.28 and 0.12 inches per day.[3] The highest value which was obtained at a constant temperature of 35°C is comparable to average midsummer pan evaporation rates for Oahu (Ekern, 1965a). The low rate was obtained at a constant temperature of 20°C and is comparable to average pan evaporation rates for December on Oahu (Ekern, 1965a).

Evaluation of pineapple response to varying thermoperiods so that comparisons of transpiration patterns could be made among the thermoperiods can be approached in two ways. Transpiration could have been corrected to the maximum atmometer rate obtained by using the percent deviation of the atmometer from the maximum under a given set of conditions. The approach taken was to adjust transpiration for fluctuations in evaporative demand by computing the transpiration-atmometer ratio. Thus if evaporative demand decreased as indicated by a reduced atmometer loss rate while transpiration remained constant,

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[3]Ekern, P. C., Honolulu, Hawaii, Personal Communication, 1969.

then transpiration should be adjusted upward to reflect the decreased evaporative demand and an assumed increase in stomatal aperature. The temperatures used bracket the growth curves for roots and tops of pineapple (Sanford, 1962). The 15°C night temperature was as low as could be maintained in the controlled environment chamber.

Two main generalizations can be made from the data obtained on the effects of varying thermoperiods on transpiration. In all cases, pineapple transpiration was uniformly low when compared with transpiration rates of nonsucculent plants as has been reported by several workers; Neales et al. (1968), Ekern (1965), Joshi et al. (1965) and others. Also, transpiration rates varied considerably throughout the light and dark periods and average light and dark rates were different for different thermoperiods. Similar results can be observed in the data of other workers who have studied the transpiration patterns of succulents (Ting et al., 1967, Neales et al., 1968, and Joshi et al., 1965). As can be seen from the data in Appendix I, plant-to-plant variation at any one measurement period was quite large.

At the 35°C day with varying night temperatures (Figure 6) two trends are apparent. First, the day ratio was relatively constant and second, the difference between average day and night ratios increased as night temperature decreased. The data indicate that at night either stomatal aperatures or the number of open stomates increased with decreasing night temperature resulting in a decrease in leaf resistance to water vapor transfer from the leaf to the environment.

Stomatal opening as indicated by transpiration was affected by temperature and by the magnitude of temperature change between day and night. The ratio consistently peaks at 1930 for the series with the peaks increasing in intensity with decreasing night temperature. The peaks and the variation for the 20°C night are attributable to plant rather than environmental fluctuations. Although not explainable, the data of Ting et al. (1967) and Neales et al. (1968) show that wide variations in leaf resistance, transpiration, and CO_2 uptake in succulents are common and reproducible.

With a 25°C day and varying night temperatures (Figure 7) the ratio increased in the afternoon indicating stomatal opening. This is consistent with the evapotranspiration data of Ekern (1965) and Neales et al. (1968) which show increased rates of CO_2 uptake and transpiration occurring towards the end of the light period. With a 25°C day temperature the ratios indicate reduced leaf resistance during the day when night temperatures were high while the reverse was true when night temperatures were low.

Effects of Thermoperiod on Day-Night Transpiration

Examination of the 24 hour period and its associated components of day and night allows comparisons to be made of the effects of different temperature regimes on the observed ratios (Figures 8, 9 and 10). With constant day-night temperatures the ratio at 35°C for the 24 hour period was significantly lower than the other temperatures. This may have been due to the higher than optimum chamber temperature. The day fraction of the above 24 hour period shows a low ratio at 35°C and a high ratio at 30°C. It appears that maximum transpiration will take place at 30°C during the day. The difference between the day and night ratios indicate that night transpiration would be expected to be lower than the day for constant day-night temperatures.

With a 35°C day and varying night temperatures the average ratio did not vary significantly for either the 24 hour or the day period. Significance is attached to the increasing ratio with a decrease in night temperature. The difference between the day and night ratios increased as the temperature difference between day and night increased. Thus a greater proportion of transpiration and carbon fixation could be expected to take place at night with lower night temperatures than with higher night temperatures.

With a 25°C day and varying night temperatures the ratios for the 24 hour period increased from 15°C to 20°C, then decreased with increasing night temperature. Maximum transpiration for a 24 hour period would be expected at a 25°C day and a 20°C night. The day transpiration/atmometer ratios increased with increasing night temperature to 30°C and then declined. The decline at 35°C was attributed to higher than optimum temperatures. Day transpiration, the ratio and assumed stomatal opening increased as night temperature increased and the trend was significant.

The night ratio at a 25°C day decreased as night temperatures increased indicating reduced leaf resistance with lower night temperatures.

The difference between day and night ratios followed a similar and highly significant pattern with the 35 and 25°C days and varying night temperatures (Figure 11). Subtracting night ratios from day ratios gave positive differences when the night temperatures were higher than or equal to day temperatures. When day temperatures were higher than

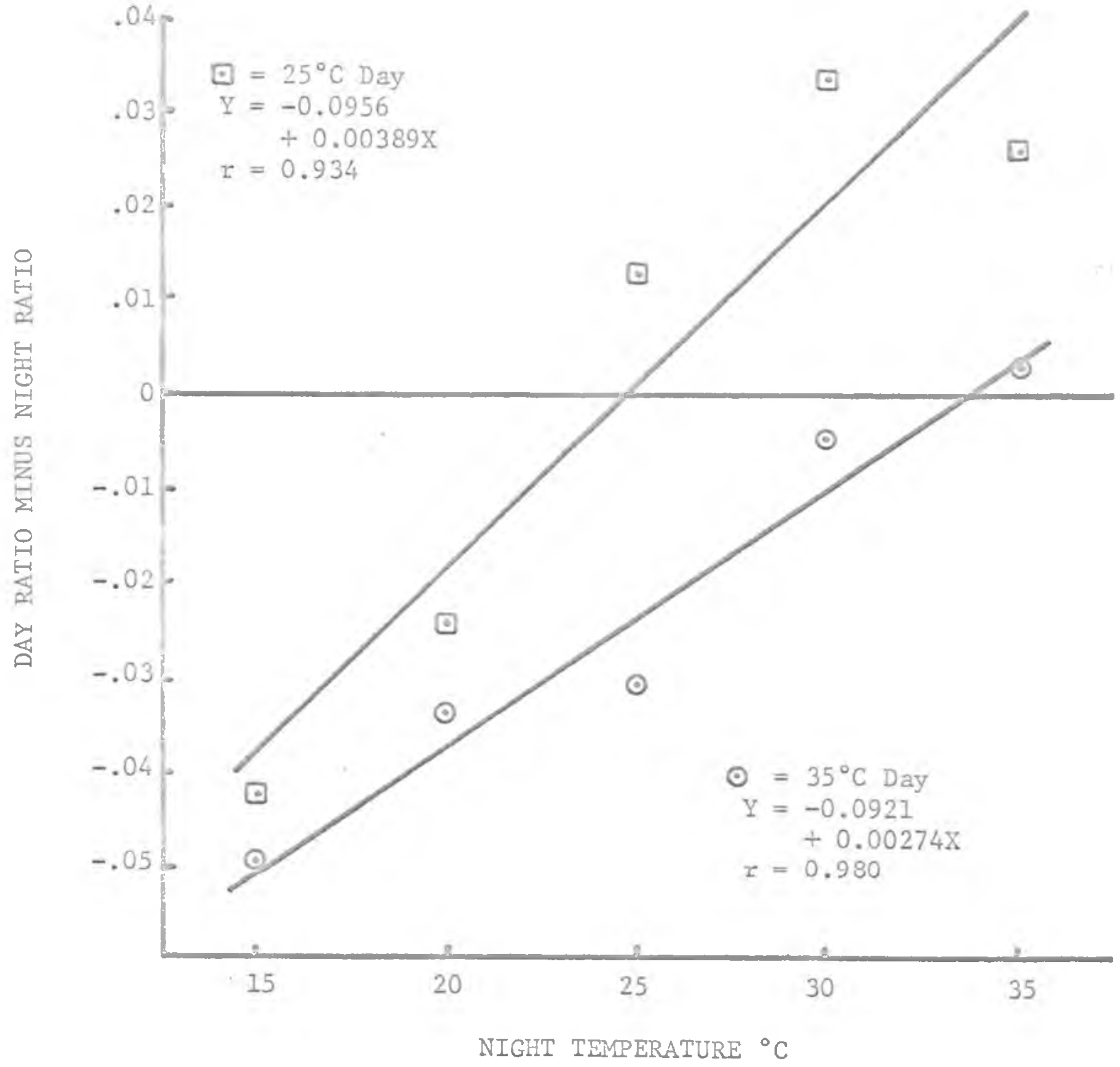

FIGURE 11. EFFECT OF NIGHT TEMPERATURE ON THE DIFFERENCE BETWEEN DAY AND NIGHT RATIO WITH TWO DAY TEMPERATURE REGIMES.

night temperatures the day ratio minus the night ratio differences were negative. The data indicate a shift from the normally expected high day-low night leaf resistance to the reverse when night temperatures equal or exceed day temperatures. These same results, when replotted against the difference between day and night temperatures, were significant at the 1% level of probability (Figure 12). The negative temperatures at the bottom indicate a night temperature higher than day temperature. A regression equation of $Y = 0.004037 - 0.003035X$ was obtained where Y equals the predicted difference in ratio and X equals day minus night temperature in °C. It is clear that a relationship exists between the difference in day and night temperatures and stomatal opening.

The predictable differences between day and night ratios and therefore, between day and night leaf resistances when day and night temperatures are shifted leads to interresting questions about pineapple water and CO_2 relations in various climates. Although it is unlikely that pineapple would ever be exposed to an environment where night temperature exceeds day temperature for more than very short periods of time, similar day-night temperatures are not too unusual at low elevations in the insular climates of Hawaii, the Philippines and Taiwan. Generally, reduced amounts of water storage tissue are found in plants growing near sea level and the ammount of tissue increases with increasing elevation and lower night temperature (Private Publication, P.R.I.). The reduction in water storage tissue in climates having little day-night temperature variation may result from increased day transpiration. What effect reduced leaf resistance during the day has

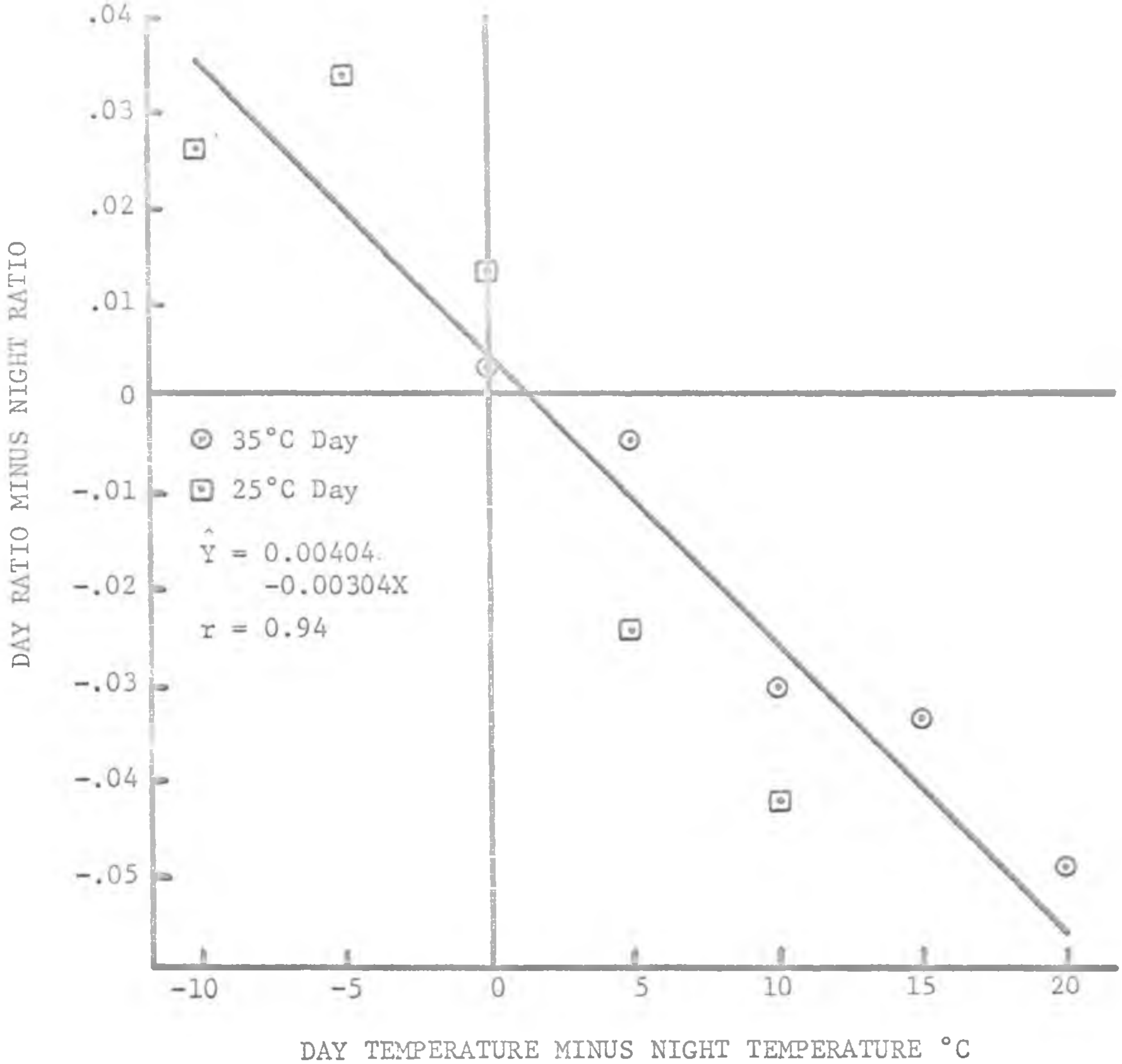

FIGURE 12. EFFECT OF THE DIFFERENCE BETWEEN DAY AND NIGHT TEMPERATURE ON THE DIFFERENCE BETWEEN DAY AND NIGHT RATIOS.

on carbon assimilation patterns is not known.

CHAPTER VI

SUMMARY

Leaf Area Determination

The relationship between leaf length and leaf area were examined for pineapple. It was found that pineapple leaf area can be satisfactorily estimated by measuring only the leaf length. Correlation coefficients as high as 0.98 were obtained between the logarithm of leaf length and logarithm of leaf area. The two clones tested had a different relationship between leaf area and leaf length and large field grown plants had a different leaf length to leaf area relationship than smaller plants of the same clone grown in the greenhouse.

Effects of Thermoperiod on Transpiration and Transpiration Atmometer Ratio

The effects of thermoperiod on transpiration and transpiration/ atmometer ratios were studied in a controlled environment chamber. Transpiration from small pineapple plants was low, never exceeding 0.3 $g/dm^2/hr$, values less than half those reported for other crop plants but still quite high for pineapple. Higher transpiration rates were obtained at 25°C than at 35°C even though prevailing evaporation rates were lower.

The ratios, which give an indication of stomatal resistance, were uniformly low during the 35°C day but increased in magnitude and variability as night temperatures were decreased from 35 to 20°C. The ratios at the 25°C day were higher and showed greater variation than was found at 35°C. When night temperatures were greater than or equal to day temperature, day ratios averaged higher than night ratios and indicate increased leaf resistance at night. When night temperature was lower than day temperature the ratios indicated high day and lower night leaf resistance.

At constant day-night temperatures, the day ratios indicate that leaf resistance decreased with increasing temperature to 30°C and then declined. At night, the ratios indicate increasing stomatal resistance with increasing night temperature. The same trend was observed for increasing night temperatures at a constant day temperature. The day-night temperature differential had a significant effect on apparent leaf resistance. Night temperature less than day temperatures resulted in decreased stomatal resistance at night with stomatal closure being indicated during the day. At night temperatures equal to or greater than day temperature, the pattern shifted to one of lowered leaf resistance during the day and high night resistance. The implications with respect to CO_2 and water relations are discussed.

APPENDIX I

TABLE A. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 35°C DAY AND 35°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$ Rep 1	Rep 2	Rep 3	Rep 4	Mean	Atmometer ml/hr
130	.072	.045	.043	.064	.056	2.4
230	.050	.045	.061	.073	.057	2.4
330	.061	.052	.043	.105	.065	2.8
430	.039	.037	.049	.016	.035	2.2
530	.044	.045	.037	.040	.042	2.8
630	.050	.052	.055	.073	.058	2.6
730	.066	.111	.097	.105	.095	6.2
830	.066	.089	.061	.105	.080	6.0
930	.061	.082	.067	.081	.073	6.4
1030	.055	.052	.049	.048	.051	6.0
1130*	.022	.037	.030	.032	.030	4.8
1230	.045	.082	.043	.056	.056	6.0
1330	.039	.126	.091	.097	.088	6.4
1430	.078	.134	.122	.161	.124	6.2
1530	.089	.134	.128	.209	.140	7.4
1630	.089	.096	.122	.161	.117	6.0
1730	.066	.111	.116	.097	.097	5.0
1830	.078	.089	.091	.129	.097	5.6
1930	.094	.074	.067	.081	.079	2.4
2030	.044	.030	.030	.048	.038	2.6
2130	.055	.037	.043	.040	.044	2.2
2230	.055	.052	.055	.081	.061	2.6
2330	.050	.037	.030	.040	.039	2.2
2430	.055	.045	.055	.064	.055	2.6
Average	.059	.071	.066	.084	.070	4.24
Leaf Area	18.06 dm^2	13.48 dm^2	16.43 dm^2	12.42 dm^2		

*Time started and finished.

APPENDIX I

TABLE B. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 35°C DAY AND 30°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.044	.063	.030	.038	.044	1.8
230	.059	.044	.042	.060	.051	2.2
330	.052	.038	.030	.038	.040	1.8
430	.030	.025	.024	.038	.027	1.8
530	.030	.019	.018	.023	.023	1.8
630	.037	.038	.036	.038	.037	3.4
730	.081	.063	.042	.060	.062	5.6
830	.096	.070	.066	.075	.077	4.2
930	.089	.076	.060	.091	.079	7.6
1030	.067	.057	.054	.083	.065	5.8
1130	.140	.082	.126	.083	.108	6.4
1230	.192	.120	.114	.181	.152	5.3
1330	.244	.184	.163	.249	.210	6.5
1430	.207	.146	.108	.219	.170	4.6
1530	.244	.171	.102	.204	.180	5.2
1630	.237	.120	.084	.181	.156	6.0
1730	.126	.114	.126	.158	.131	7.2
1830	.126	.076	.102	.113	.104	4.2
1930	.155	.120	.078	.128	.120	2.2
2030	.074	.063	.048	.060	.061	1.6
2130	.067	.038	.036	.060	.050	1.8
2230	.074	.076	.060	.060	.068	1.9
2330*	.067	.051	.048	.053	.055	1.8
2430	.044	.013	.036	.045	.035	2.2
Average	.170	.078	.069	.098	.088	3.83
Leaf Area	13.52 dm^2	15.80 dm^2	16.61 dm^2	13.25 dm^2		

*Time started and finished.

APPENDIX I

TABLE C. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 35°C DAY AND 25°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.081	.068	.059	.079	.072	1.6
230	.066	.068	.066	.066	.067	1.4
330	.081	.062	.066	.066	.069	1.6
430	.066	.068	.059	.059	.063	1.8
530	.081	.043	.037	.040	.050	1.4
630	.022	.049	.022	.053	.037	1.3
730	.051	.043	.081	.053	.057	5.3
830	.074	.055	.066	.073	.067	6.0
930	.059	.043	.051	.059	.053	5.6
1030	.066	.043	.059	.053	.055	5.4
1130*	.052	.043	.037	.040	.043	5.0
1230	.052	.031	.037	.046	.042	4.8
1330	.192	.055	.081	.059	.097	6.2
1430	.059	.086	.088	.059	.073	4.8
1530	.162	.074	.088	.093	.104	5.9
1630	.103	.074	.095	.066	.085	5.5
1730	.066	.074	.022	.053	.054	5.4
1830	.074	.018	.088	.059	.060	5.0
1930	.133	.154	.147	.112	.137	1.6
2030	.052	.025	.044	.059	.045	1.7
2130	.066	.062	.051	.073	.063	2.1
2230	.081	.080	.095	.073	.082	1.9
2330	.103	.080	.073	.099	.089	1.9
2430	.066	.080	.073	.059	.070	1.6
Average	.077	.062	.066	.064	.067	3.53
Leaf Area	13.56 dm^2	16.24 dm^2	13.67 dm^2	15.13 dm^2		

*Time started and finished.

APPENDIX I

TABLE D. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 35°C DAY AND 20°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.110	.133	.098	.115	.114	1.9
230	.081	.061	.078	.107	.083	2.3
330	.103	.079	.059	.183	.106	1.6
430	.066	.052	.052	.008	.045	1.8
530	.066	.061	.059	.076	.066	2.0
630	.000	.079	.176	.122	.094	4.8
730	.213	.061	.000	.107	.095	5.8
830	.095	.105	.170	.122	.123	7.6
930	.081	.079	.000	.061	.055	6.4
1030	.081	.044	.085	.168	.095	7.8
1130*	.103	.070	.085	.115	.094	6.0
1230	.037	.044	.124	.038	.061	7.4
1330	.051	.000	.039	.053	.036	6.7
1430	.059	.052	.078	.076	.066	6.8
1530	.073	.096	.026	.076	.068	7.4
1630	.059	.079	.105	.069	.078	6.1
1730	.059	.061	.052	.198	.093	7.0
1830	.015	.044	.033	.145	.059	7.0
1930	.066	.061	.033	.130	.073	0.8
2030	.015	.061	.046	.099	.055	1.7
2130	.154	.140	.092	.252	.159	1.7
2230	.081	.079	.092	.122	.094	1.9
2330	.184	.113	.092	.198	.147	1.7
2430	.044	.087	.092	.168	.098	1.8
Average	.079	.072	.074	.117	.085	4.42
Leaf Area	13.61 dm^2	11.45 dm^2	15.30 dm^2	13.10 dm^2		

*Time started and finished.

APPENDIX I

TABLE E. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 25°C DAY AND 35°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.077	.080	.069	.054	.070	4.0
230	.085	.080	.092	.063	.080	4.1
330	.085	.107	.092	.072	.087	4.2
430	.102	.107	.115	.090	.104	4.2
530	.111	.107	.099	.099	.104	4.4
630	.179	.232	.222	.171	.201	5.4
730	.136	.161	.168	.126	.148	3.4
830	.162	.205	.122	.090	.145	4.3
930	.136	.152	.207	.135	.158	4.0
1030	.136	.169	.099	.081	.121	3.7
1130*	.111	.125	.161	.090	.122	3.4
1230	.170	.223	.145	.090	.157	4.1
1330	.221	.205	.275	.189	.223	4.3
1430	.221	.286	.199	.198	.226	3.9
1530	.238	.268	.253	.225	.246	4.0
1630	.221	.259	.191	.171	.211	3.9
1730	.213	.232	.199	.180	.206	3.9
1830	.085	.125	.084	.063	.089	2.4
1930	.085	.079	.069	.063	.074	2.0
2030	.060	.062	.054	.054	.058	3.2
2130	.060	.054	.046	.045	.051	5.2
2230	.060	.062	.054	.027	.051	4.4
2330	.051	.062	.054	.045	.053	4.0
2430	.068	.074	.061	.054	.064	4.1
Average	.129	.146	.130	.103	.127	3.90
Leaf Area	11.75 dm^2	11.20 dm^2	13.07 dm^2	11.13 dm^2		

*Time started and finished.

APPENDIX I

TABLE F. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 25°C DAY AND 30°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.086	.102	.075	.080	.086	1.9
230	.086	.102	.068	.098	.088	2.9
330	.075	.119	.075	.080	.087	2.9
430	.096	.119	.090	.089	.099	3.2
530	.075	.102	.083	.098	.089	3.0
630	.150	.213	.136	.179	.169	3.2
730	.203	.255	.151	.250	.215	2.8
830	.118	.230	.098	.197	.160	2.9
930	.150	.162	.166	.206	.171	3.1
1030	.086	.213	.143	.161	.150	3.2
1130*	.139	.162	.136	.206	.160	3.0
1230	.096	.077	.106	.152	.108	3.1
1330	.160	.187	.106	.132	.151	2.9
1430	.182	.221	.158	.268	.207	2.9
1530	.203	.272	.158	.277	.228	2.5
1630	.214	.255	.203	.277	.237	3.0
1730	.246	.315	.173	.241	.244	3.1
1830	.096	.111	.045	.107	.090	1.0
1930	.086	.094	.113	.098	.098	2.3
2030	.053	.068	.008	.045	.043	2.6
2130	.043	.060	.083	.063	.062	3.0
2230	.075	.077	.060	.071	.071	2.8
2330	.064	.077	.053	.063	.064	2.8
2430	.064	.085	.053	.071	.068	3.9
Average	.119	.153	.106	.146	.131	2.84
Leaf Area	9.35 dm^2	11.76 dm^2	13.27 dm^2	11.19 dm^2		

*Time started and finished.

APPENDIX I

TABLE G. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 25°C DAY AND 25°C NIGHT TEMPERATURE

Time	Transpiration g/dm^2/hr					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.062	.048	.067	.049	.057	1.3
230	.077	.062	.076	.049	.066	1.4
330	.039	.062	.084	.057	.061	1.3
430	.054	.055	.067	.049	.057	1.4
530	.046	.055	.059	.049	.052	1.4
630	.124	.152	.126	.082	.121	1.9
730	.108	.118	.278	.107	.153	3.3
830	.116	.118	.101	.090	.106	3.2
930	.124	.132	.152	.099	.126	3.2
1030	.093	.097	.135	.090	.104	3.2
1130*	.108	.104	.135	.123	.118	3.1
1230	.124	.111	.202	.164	.150	3.2
1330	.209	.249	.320	.213	.248	3.4
1430	.271	.256	.337	.222	.271	3.1
1530	.217	.208	.295	.189	.227	2.8
1630	.225	.215	.278	.205	.231	3.1
1730	.186	.201	.219	.279	.221	3.2
1830	.132	.125	.143	.025	.106	1.9
1930	.062	.069	.101	.082	.079	1.2
2030	.085	.076	.084	.074	.080	1.4
2130	.054	.055	.076	.049	.059	1.2
2230	.062	.062	.067	.057	.062	1.3
2330	.077	.055	.067	.057	.064	1.3
2430	.031	.062	.067	.041	.050	1.4
Average	.111	.114	.146	.103	.118	2.20
Leaf Area	12.91 dm^2	14.44 dm^2	11.87 dm^2	12.18 dm^2		

*Time started and finished.

APPENDIX I

TABLE H. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 25°C DAY AND 20°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$ Rep 1	Rep 2	Rep 3	Rep 4	Mean	Atmometer ml/hr
130	.081	.077	.075	.064	.074	1.0
230	.069	.067	.068	.055	.065	1.2
330	.104	.067	.075	.055	.075	1.1
430	.104	.067	.075	.055	.075	1.1
530	.069	.057	.053	.055	.059	1.0
630	.139	.096	.106	.083	.106	2.4
730	.127	.077	.075	.073	.088	2.8
830	.150	.067	.106	.083	.101	3.0
930	.115	.086	.083	.083	.092	3.2
1030	.196	.077	.098	.083	.113	3.1
1130*	.219	.105	.121	.129	.143	2.9
1230	.092	.077	.098	.101	.091	2.9
1330	.150	.144	.158	.174	.157	3.2
1430	.173	.124	.181	.165	.161	2.9
1530	.150	.134	.128	.156	.142	3.1
1630	.162	.105	.136	.138	.135	3.1
1730	.139	.105	.113	.138	.124	3.0
1830	.104	.077	.106	.092	.094	2.4
1930	.081	.057	.091	.055	.071	1.0
2030	.092	.096	.091	.073	.088	0.8
2130	.104	.086	.113	.064	.092	1.0
2230	.081	.086	.075	.073	.079	1.2
2330	.092	.086	.098	.055	.083	1.0
2430	.115	.086	.075	.073	.088	1.0
Average	.121	.088	.100	.091	.100	2.06
Leaf Area	8.66 dm^2	10.45 dm^2	13.25 dm^2	10.89 dm^2		

*Time started and finished.

APPENDIX I

TABLE I. HOURLY TRANSPIRATION AND ATMOMETER RATES FOR A 25°C DAY AND 15°C NIGHT TEMPERATURE

Time	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
130	.070	.065	.101	.076	.078	1.1
230	.096	.092	.074	.057	.080	1.1
330	.078	.074	.111	.076	.085	1.0
430	.087	.083	.083	.057	.079	1.0
530	.105	.074	.074	.038	.073	1.0
630	.096	.074	.092	.095	.089	1.2
730	.087	.092	.092	.104	.094	2.4
830	.087	.083	.101	.076	.087	2.9
930	.061	.065	.092	.076	.073	3.3
1030	.087	.074	.083	.066	.078	3.0
1130*	.078	.074	.083	.076	.078	2.9
1230	.052	.074	.055	.028	.052	3.1
1330	.078	.046	.074	.057	.064	3.1
1430	.131	.120	.083	.085	.105	3.0
1530	.105	.139	.203	.114	.140	3.0
1630	.139	.120	.175	.104	.135	3.0
1730	.131	.111	.129	.095	.116	3.0
1830	.087	.102	.129	.085	.101	3.0
1930	.026	.037	.074	.047	.046	1.0
2030	.113	.083	.092	.057	.086	1.2
2130	.070	.055	.092	.085	.076	1.0
2230	.096	.102	.083	.076	.089	1.0
2330	.070	.074	.101	.076	.080	1.1
2430	.096	.074	.074	.057	.075	0.9
Average	.092	.082	.103	.074	.088	2.01
Leaf Area	11.47 dm^2	10.82 dm^2	10.85 dm^2	10.54 dm^2		

*Time started and finished.

APPENDIX II

TABLE A. 24 HOUR TRANSPIRATION AND ATMOMETER RATES FOR ALL TEMPERATURE REGIMES

Temperature Regime Day-Night °C	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
35-35	.059	.071	.066	.084	.070	4.24
35-35*	.090	.065	.118	.139	.103	4.35
35-30	.107	.078	.069	.098	.088	3.83
35-25	.077	.062	.066	.064	.067	3.53
35-20	.079	.072	.074	.117	.085	4.42
35-15*	.055	.065	.046	.041	.052	2.40
30-30*	.139	.133	.142	.155	.142	3.09
25-35	.129	.146	.130	.103	.127	3.90
25-30	.119	.153	.106	.146	.131	2.84
25-25	.111	.114	.146	.103	.118	2.20
25-25*	.068	.075	.102	.110	.089	2.47
25-20	.121	.088	.100	.091	.100	2.06
25-15	.092	.082	.103	.074	.088	2.01
20-20*	.087	.073	.079	.091	.083	1.80

*Gravimetric water loss taken twice daily at lights on and lights off.

APPENDIX II

TABLE B. DAY TRANSPIRATION AND ATMOMETER RATES FOR ALL TEMPERATURE REGIMES

Temperature Regime Day-Night °C	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
35-35	.061	.095	.085	.107	.087	6.00
35-35*	.130	.075	.165	.208	.145	4.93
35-30	.154	.107	.096	.142	.124	5.70
35-25	.079	.053	.066	.059	.064	5.41
35-20	.077	.061	.061	.102	.075	6.83
35-15*	.059	.085	.052	.048	.061	4.14
30-30*	.207	.206	.196	.228	.209	3.23
25-35	.172	.201	.175	.136	.171	3.69
25-30	.158	.205	.137	.208	.177	2.81
25-25	.158	.159	.213	.148	.169	3.02
25-25*	.081	.110	.151	.169	.128	2.92
25-20	.148	.098	.117	.118	.120	2.97
25-15	.101	.091	.116	.080	.097	2.98
20-20*	.107	.102	.100	.130	.110	2.41

*Gravimetric water loss taken twice daily at lights on and lights off.

APPENDIX II

TABLE C. NIGHT TRANSPIRATION AND ATMOMETER RATES FOR ALL TEMPERATURE REGIMES

Temperature Regime Day-Night °C	Transpiration $g/dm^2/hr$					Atmometer
	Rep 1	Rep 2	Rep 3	Rep 4	Mean	ml/hr
35-35	.056	.045	.047	.060	.052	2.48
35-35*	.050	.055	.072	.071	.062	3.77
35-30	.061	.050	.042	.054	.052	1.96
35-25	.075	.070	.066	.070	.070	1.66
35-20	.081	.082	.086	.132	.095	2.00
35-15*	.051	.046	.039	.033	.042	0.66
30-30*	.070	.060	.088	.083	.075	2.95
25-35	.085	.092	.085	.070	.083	4.10
25-30	.079	.101	.075	.085	.085	2.88
25-25	.065	.068	.079	.058	.067	1.38
25-25*	.056	.041	.054	.051	.051	2.02
25-20	.094	.077	.083	.064	.080	1.15
25-15	.084	.074	.089	.067	.078	1.05
20-20*	.068	.044	.058	.051	.055	1.18

*Gravimetric water loss taken twice daily at lights on and lights off.

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